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Establishment and production from thinned mature deciduous-forest silvopastures in Appalachia

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Abstract Small Appalachian hill farms may benefit economically by expanding grazing lands into some of their under-utilized forested acreages. Our objective was to study the forage production potential of forest to silvopasture conversion. We thinned a white oak dominated mature second growth forested area establishing two orchardgrass-perennial ryegrass-white clover silvopasture replications for comparison with two nearby open pasture replications. After thinning trees, silvopastures were limed, fertilized and seeded. Sheep were fed hay and corn scattered across the area to facilitate removal of residual understory vegetation, disruption of litter layer and incorporation of applied materials into surface soil. Each area was divided into multiple paddocks and rotationally grazed by sheep. Two 1 m^2 herbage mass samples were taken from each paddock prior to animal grazing. There was no significant difference in soil moisture between silvopastures and open pastures however, there was adequate rainfall to prevent drought all 3 years. The two silvopastures received 42 and 51% of total daily incident PAR compared to the open field. Total dry forage mass yield from open pasture over the 3 years averaged 11,200 kg ha^{-1} y^{-1} and from silvopasture 6,640 kg ha^{-1} y^{-1}. Silvopastures, however, had a higher PAR use efficiency (PARUE) than open pasture. Hill farms could increase grazing acreages without sacrificing all benefits from trees on the landscape by converting some areas to silvopasture.

Keywords C_3 forage · PAR · Rotational grazing · Woodlot

Disclaimer Mention of equipment does not imply endorsement by USDA-ARS but is supplied to inform readers of how data was acquired.

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Introduction

Farming in Appalachia has been traditionally closely linked to managing woody vegetation. Forests provided game animals, livestock fodder, seasonal specialty edibles, medicinals, timber and firewood. Also, allowing fields to be reclaimed by woody vegetation accumulated nutrients in the biomass that was burned for ash that renewed field crop fertility (Barnes 1938; Otto 1983). Throughout the 20th century forest management increasingly emphasized wood production at the expense of other traditional products (Garrett et al. 2004). Animals have been frequently allowed access to deciduous woodlots although little has been done to manage woodlots for forage production. In fact, Chandler (1940) states "It is widely recognized that the grazing of farm woodlands in the eastern United States is an undesirable practice".

In recent decades there is an emerging interest within the eastern US in developing deciduous-tree based silvopastoral systems to increase and diversify the income of small farms. These systems also provide potential environmental services such as microclimate modification for forages and livestock, improved wildlife habitat, carbon sequestration, and capture and recycling of nutrients leached below the forage root zone. A number of research projects have shown the positive potential for Appalachian silvopastures in the last two decades by planting trees such as black walnut (*Juglans nigra* L.), black locust (*Robinia pseudoacacia* L.), or honey locust (*Gleditsia triacanthos* L.) into existing pastures (Buergler et al. 2005; Feldhake et al. 2008).

However, there are many small farms in Appalachia with woodlots that are little utilized and farm income could be increased if guidelines were available for conversion of some acreage into productive silvopastures. Thinning these areas would have the added benefit of releasing the most desirable trees on many sites for improved growth as timber trees (Godsey et al. 2007). The objective of this research was to study the response of forages, managed for grazing, in thinned hardwood stands.

Materials and methods

The research site was on a small hill-farm in southern West Virginia, USA (37°46′W 81°00′N 860 m.a.s.l.). The soil at the experimental site was classified as a Dekalb (fine sandy loam, mixed, mesic Typic Hapludult). Two silvopasture areas were established within a white oak (*Quercus alba* L.) dominated, approximately 70 year old, dense, mature second growth forest. Individual trees averaged 25 m in height and 0.45 m in diameter at breast height (DBH). The first silvopasture replication site (S1), of 0.4 ha, was established in 2002 and divided into eight uniformly sized grazing paddocks. The second replication site (S2), established in 2003, was 0.6 ha and divided into 12 uniformly sized grazing paddocks. The areas were thinned to a target tree basal area of 17 m^2 ha^{-1}, fenced and grazed by crossbred wether sheep (approximate live weight, 75 kg) to remove the understory vegetation and break up the litter layer. Hay and shelled corn were scattered uniformly over the area to promote trampling by animals for site preparation. Prior to forage establishment soil samples were taken for nutrient and pH assessment. Dolomitic lime was surface applied to achieve a target pH of 6.2. Phosphorus (as P_2O_5) was surface applied to achieve 34 kg ha^{-1} Bray P, an estimate of plant available P for acid soils (Bray and Kurtz 1945). During the establishment year, starter fertilizer applications of 112 kg K ha^{-1} and 34 kg N ha^{-1} were applied. All sites received 34 kg N ha^{-1} each subsequent spring. The sheep were removed while the area was limed, fertilized, and seeded. Seeds were sown onto silvopasture sites using a hand operated cyclone seeder to apply 8.4 kg ha^{-1} orchardgrass (*Dactylis glomerata* L.; variety Benchmark), 6.2 kg ha^{-1} white clover (*Trifolium repens* L.; cultivar Huia) and 4.3 kg ha^{-1} each of two varieties of perennial ryegrass (*Lolium perenne* L.; varieties Elf and Seville). The area was again applied with hay and shelled corn and sheep introduced to feed while trampling in the forage seed.

Two nearby open pasture replication sites (O1 and O2) that had been grazed for many decades were fenced into paddocks in 2002 and 2003, respectively. There were more paddocks at O1 and O2 than at S1 and S2 to accommodate additional grazing experiments. For this experiment a replication consisted of five paddocks rotationally grazed with each paddock grazed for 1 week before moving animals. Replications at S1 and O1 were rotationally grazed by sheep during 2004, 2005, and 2006 and at S2 and O2 in 2005 and 2006. Two 1 m^2 herbage mass samples were clipped from each paddock prior to animal grazing then dried and weighed. Paddocks were rotationally grazed by four test animals with extra animals added as needed to ensure each paddock was reduced to about a 5 cm height within 1 week. Animal response data is not fully analyzed and will be reported at another time so for this paper animals are considered forage mowers.

Soil moisture was measured for the top 15 cm in a 24 point grid in all four sites whenever more than a week passed without precipitation using a TRIME-FM portable TDR soil moisture meter (MESA Instruments, Medfield, MA). Photosynthetically active radiation (PAR) was measured for a week period between DOY 188 and 222 for the S1 and S2 replications, the dates differing with year, using a system of 16 LI-COR LI-191-SB line quantum sensors (LI-COR, Lincoln, NE) and 21× data loggers (Campbell Scientific Logan, UT). A weather station in an adjacent open field measured air temperature, precipitation, solar radiation (Kipp and Zonen CM3 pyranometer, Belft, Holland) and PAR (LI-190 SB quantum sensor, LI-COR, Lincoln, Nebraska, USA) using a 23× data logger and these PAR data were used as the unshaded value for the two open pasture replications.

The ratio of total incident solar radiation to energy needed to evaporate precipitation for incremental 10 day time periods was calculated using

$$E_r = R_i / P_c \lambda k \quad (1)$$

where R_i is total 10 day solar radiation (MJ 10 d^{-1} m^{-2}), P_c is total 10 day precipitation (mm 10 d^{-1} m^{-2}), λ is latent heat of vaporization (2.45 MJ kg^{-1} at 20°C) and k is the mass of water in 1 mm of precipitation (1 kg mm^{-1} m^{-2}). Assuming 75% of solar radiation is net radiation (Rosenberg 1974), and dew provides 20% of water for daily evapotranspiration (Glenn et al. 1996, Rosenberg 1974), then $E_r < 1.8$ indicated adequate precipitation for optimal forage growth.

During an overcast summer day with full tree foliage expansion, upward hemispherical images were photographed in the center of each grazing paddock using a Nikon Coolpix 995 digital camera with a Nikon FC-E8 Fisheye Converter and a self-leveling mount. Images were analyzed for open sky percent field-of-view and potential direct-beam transmitted solar radiation through the tree canopy as a function of day-of-year (DOY) using WinSCANOPY software (Regent Instruments Inc., Quebec Canada).

The PAR use efficiency (PARUE) was calculated by dividing the clipped and dried forage mass by the total PAR received during the growing period. The growing period was from the date the animals were removed from the paddock until a clipping was made the day before the animals were returned. The PAR for the grazing periods at O1 and O2 was summed from values measured at the weather station in the open field adjacent to the study area. The PAR at S1 and S2 was determined by multiplying the values summed from the weather station data by the respective percent transmitted through the tree canopies determined using the light bar data. The values for PARUE were only calculated after DOY 160 to ensure forages grew under a fully developed tree canopy in S1 and S2 and before DOY 270 to ensure falling leaves and changes in leaf color did not result in changing light conditions.

Differences in yield and PARUE between sites were tested for significance using one way analysis of variance and Tukey's comparison of means.

Results

The climate at this research site is humid and temperate. Due to its moderately high elevation (860 m) it is generally cool and is ideally suited for growing cool season (C_3) forages. During the 3 years of this study the 10 day average maximum temperatures never exceeded 28.5°C (Table 1). The cloudiness is highly variable so while the seasonal peak in

Table 1 Maximum average daily temperature (T_{max}) and the ratio of incident solar radiation to the energy equivalent needed to evaporate precipitation (E_r) for 10 day incremental periods of 2004, 2005, and 2006. The DOY shown is the ending date of each measurement period

DOY	T_{max} (°C)			E_r		
	2004	2005	2006	2004	2005	2006
110	15.5	19.1	22.4	0.67	11	1.4
120	21.2	14.6	19.1	1.5	0.89	1.6
130	20.8	15.9	17.2	3.4	3.3	3.9
140	25.9	22.0	16.5	1.6	1.2	2.2
150	25.1	18.2	22.7	0.99	1.2	20
160	21.3	23.2	23.3	0.42	3.4	2.3
170	26.7	24.5	22.3	0.82	2.7	1.9
180	22.9	26.2	25.5	0.67	5.1	0.63
190	26.2	25.9	24.7	4.3	0.82	2.0
200	24.7	26.6	27.7	1.8	1.1	1.5
210	25.0	28.5	27.2	0.55	0.62	3.5
220	24.4	28.0	28.5	1.2	2.3	1.2
230	22.4	28.1	25.2	3.2	1.2	0.94
240	25.2	24.5	26.7	4.8	0.75	20
250	25.9	23.8	21.3	20	11	0.56
260	23.0	26.0	20.8	0.49	20	4.8
270	22.4	24.7	19.0	0.58	1.2	1.2
280	19.1	22.6	19.4	0.74	7.5	0.69
290	17.5	18.4	15.0	2.5	0.55	1.0
300	16.6	14.9	12.1	0.55	0.72	0.59

A maximum value of 20 was used for E_r when precipitation was only a trace or zero

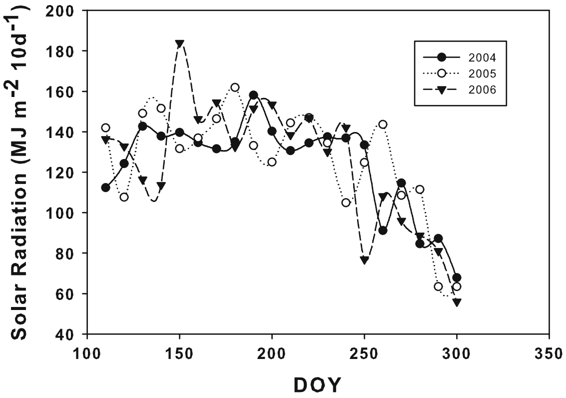

Fig. 1 Total 10 day solar radiation values from DOY 100 to 300 for 2004, 2005 and 2006

solar radiation is near the summer solstice (DOY 171) there was considerable variability in 10 day averages (Fig. 1). Precipitation averages 1.1 m per year and is uniform across the year therefore some years it does not supply evapotranspirational demand during high solar radiation months. The 3 years of this study had high precipitation levels and most 10 day periods had $E_r < 1.8$ with very few substantially higher values. Minimum volumetric soil moisture for the few measurement periods without precipitation was 25% for the silvopasture and 24.1% for the open pasture (versus 31% at approximate field capacity after rainfall) and the difference was not statistically significant between treatments and replications.

The actual tree basal area for S1 and S2 was 16.5 and 17.0 m^2 ha^{-1}, respectively (Table 2). The amount of open sky determined from the hemispheric lens photos was 22.4 and 21.0% for S1 and S2. However, trees cast the most shade early and late in the day when solar radiation levels are low. The greatest amount of open sky in the field of view is directly overhead. Midday solar radiation levels, when the sun position is closest to directly overhead, are high so solar radiation percent transmitted is greater than percent open field of view. Actual PAR measured with the light bars was biased since it was measured at S1 and S2 on different dates. A uniform sub set of 12 measurement dates was chosen for both sites from PAR daily totals measured at the weather station ranging from 23 to 47 mol $d^{-1}m^{-2}$. For S1 the average of dates chosen was 35.2 mol $d^{-1}m^{-2}$ with a standard deviation of 7.8 mol $d^{-1}m^{-2}$ and for S2 the average was 35.4 mol $d^{-1}m^{-2}$ with a standard deviation of 8.0 mol $d^{-1}m^{-2}$. For these dates the percent PAR transmitted to the forage canopies in S1 and S2 averaged 42 and 51%, respectively (Table 2). The reason for a greater difference in percent PAR transmitted between the two sites compared to the difference in percent open sky is that the south side of S1 was adjacent to an unthinned forest and the south side of S2 was adjacent to an open lane with a gravel driveway. This resulted not only in a greater levels of PAR transmitted along the southern side of S2 but also a greater standard deviation across the site (Table 2).

The seasonal patterns in forage yields were similar all 3 years (Fig. 2a, b, c). The greatest yields were prior to DOY 150 during the spring growth flush. Individual harvest yields for O1 and O2 were generally greater than for S1 and S2 although there was overlap. Total seasonal yields were significantly smaller in silvopastures than in open pasture, averaging 59% (Table 3). The average yield of silvopastures during the period with full tree leaf canopies was also 59% of open pasture yield. The yields from O2 were significantly greater than for O1 (18%).

There was a trend for individual harvests to have greater PARUE in S1 and S2 compared to O1 and O2 (Fig. 3a, b, c). Average PARUE when trees were with a full leaf canopy (Table 3) was generally greater in

Table 2 Treatment designation, tree basal area for the four grazing paddock areas, percent open sky over forages with standard deviation for silvopastures (SD), percent of maximum photosynthetically active radiation (*PAR*) incident during the measurement periods as a result of cloud attenuation, percent of measured incident PAR reaching forage canopies with standard deviation for silvopastures (SD), and actual percent of maximum possible PAR reaching forage canopies

Treatment	Basal area (m^2 ha^{-1})	Open sky (SD) (%)	With clouds (%)	Under trees (SD) (%)	Actual (%)
O1	0	100	63	100	63
O2	0	100	62	100	62
S1	16.5	22.4 (5.6)	63	42 (3)	26
S2	17.0	21.0 (4.7)	62	51 (7)	32

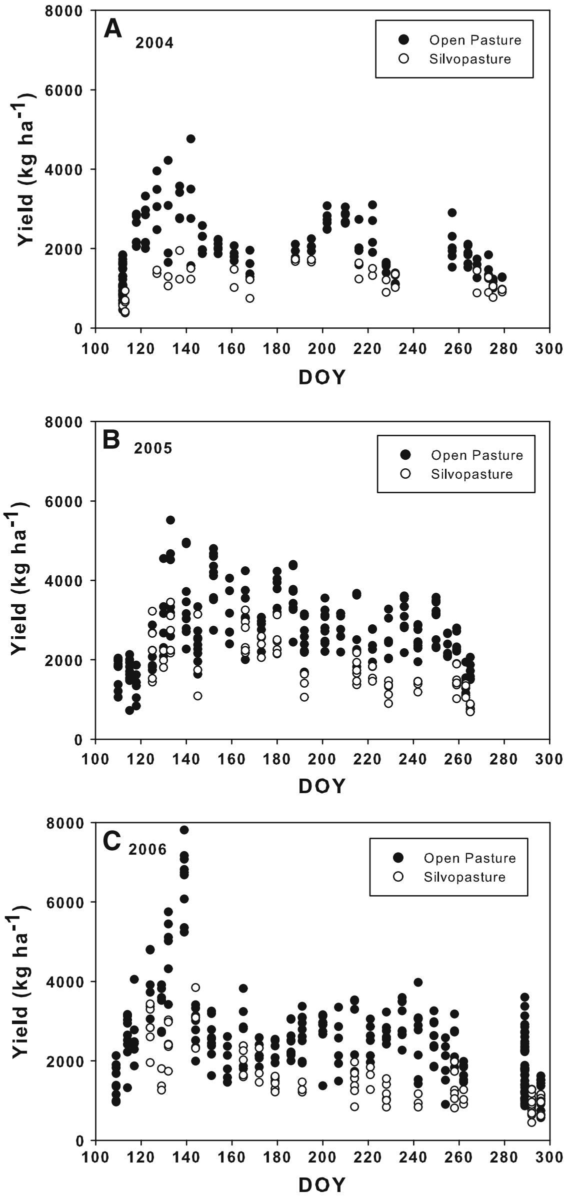

Fig. 2 Yield for open pasture and silvopasture plots determined before each grazing event for **a** 2004, **b** 2005 and **c** 2006. Each point is the mean of two samples

silvopasture than in open pasture although in 2006 S2 was numerically but not significantly higher than O2.

Discussion

Establishing silvopastures in existing forests presents challenges, expenses and opportunities (Godsey et al. 2007). Second growth forests are frequently dense

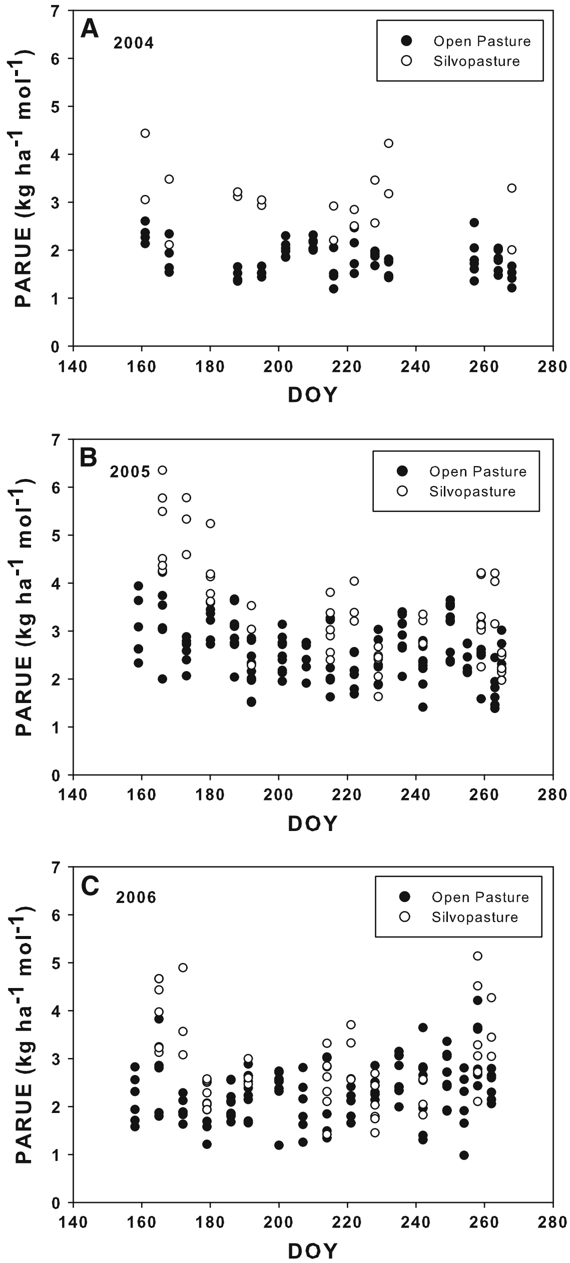

Fig. 3 Photosynthetically active radiation use efficiency (*PARUE*) for open pasture and silvopasture plots during the full tree leaf canopy period (DOY 160–270) of **a** 2004, **b** 2005 and **c** 2006. Each point is the mean of two harvest samples

stands resulting in inferior growth of individual trees. Thinning the stand thus releases the most desirable trees freeing up resources and facilitating improved growth by the remaining trees. Frequently the thinnings can be sold as pulpwood or firewood generating some income to off-set costs and livestock grazing

Table 3 Total dry mass yield from DOY 100–300, mean harvest dry mass yield from DOY 160–270 with full tree leaf canopy, photosynthetically active radiation use efficiency (*PARUE*) from DOY 160–270 for harvests of two replications of open pasture (O1 and O2) and silvopastures (S1 and S2) and the ratio of silvopasture to open pasture for 2004, 2005 and 2006

	O1	O2	S1	S2	S/O
DOY 100–300 total yield (kg m^{-2})					
2004	9720 a		5640 b		0.58
2005	9920 b	11200 a	5970 c	7640 c	0.64
2006	11000 b	14100 a	6580 c	7350 c	0.55
DOY 160–270 mean yield (kg m^{-2})					
2004	2020 a		1320 b		0.65
2005	2550 b	3030 a	1590 c	1720 c	0.59
2006	2350 b	2760 a	1360 c	1490 c	0.56
DOY 160–270 PARUE (kg m^{-2} mol^{-1})					
2004	1.82 b		3.03 a		1.66
2005	2.46 c	2.89 b	3.73 a	3.35 a	1.32
2006	2.26 c	2.50 bc	3.09 a	2.85 ab	1.25

Values along horizontal rows followed by the same letter are not significantly different with Tukey's (HSD) comparison of means

can generate a steady income stream while the remaining trees gain value.

Developing silvopastures from existing forest presents challenges that differ greatly from developing silvopastures by planting trees in existing pasture. In Appalachia many soils are highly weathered and shallow. Silvopasture soil pH for the top 15 cm was 5.5, having increased from 4.7 prior to liming, while in pastures managed for many decades the pH was 6.8 (Staley et al. 2008). Bray I extractable soil P was also significantly higher for pasture compared to silvopasture with values of 35.8 and 27.7 mg kg^{-1}, respectively compared to 6.1 mg kg^{-1} for silvopasture prior to fertilization. For this reason differences in PAR were likely not solely responsible for differences in yield between open pasture and silvopasture. Minimal forage yield differences were found in response to shading by trees planted in rows within existing Appalachian pastures (Buergler et al. 2005; Feldhake et al. 2008). Had these oak silvopasture soils been managed historically the same as the open pastures there may have been less forage yield difference. However soil differences between forests and open pasture in Appalachia is often one of the realities to manage in establishing this type of silvopasture.

One purported advantage of deciduous tree silvopastures to conifer silvopastures is that deciduous trees shed their leaves allowing greater PAR penetration through the tree canopy during winter and early spring. In this study there was no pattern of greater silvopasture forage yield in spring before complete tree leaf emergence than after tree leaf emergence (Fig. 2a, b, c). The early yields in the silvopasture were so low in early 2004 prior to the beginning of tree leaf emergence (DOY 120) that in 2005 and 2006 the first grazing rotation was scheduled about 20 days later in the silvopastures than in the open pastures. The likely cause is that white oak has leaves that are slow to decompose and continue to shade forages after autumn while laying senesced on the ground. After the first grazing cycle in the spring they have less impact since sheep hooves shred them facilitating movement to the soil surface.

Forage production differences between silvopasture and open pasture were compared in this study under conditions of generally favorable soil water and not tested under drought. While E_r for some 10 day periods was higher than 1.8, soil moisture was never measured below 25% for the silvopasture and 24.1% for open pasture. By comparison, prior to the establishment of S2 and O2 replications, in 2002 there was an extended dry period and soil moisture at S1 and O1 was below 15% for a several week period. There were only 13 out of 60 periods with $E_r > 3.6$, indicating less than half of required precipitation was received to meet evapotranspiration demand. However, prior to these periods E_r was generally lower than 1.8 facilitating good soil water storage entering precipitation deficit periods.

The yield variability between paddocks at any harvest time was substantial for both the open pastures and the silvopastures. It varied by a factor of 2–3 for harvest dates (Fig. 2a, b, c). This may be related to soil variability but also possibly due to animal trampling damage since animals choose areas in which to congregate when not actively grazing which would affect yield sampling for the subsequent cycle. The PARUE was higher in the silvopastures which is consistent with research showing that tree shaded forages utilize PAR for leaf growth more efficiently than unshaded (Feldhake and Belesky 2009) although in that study forages were placed in the ground in pots with a prepared, uniform growth medium and also were not grazed.

Conclusions

Opening dense maturing regrowth deciduous forests to expose 22% open sky allowed 47% penetration of daily incident PAR and permitted forage production of 59% compared to open pasture. Seasonal and short term weather patterns in the humid Appalachia resulted in considerable variability in incident radiation so percent solar radiation penetration alone is not an accurate measure of actual PAR available for forage growth.

However, the pasture sites with which silvopastures were compared had soils managed for forage production for many decades and the sites left in forest were likely considered inferior for pasture. The silvopasture soils had only been limed and fertilized for a few years, therefore, tree shade may not have been solely responsible for less yield from silvopastures compared to adjacent open pastures.

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